Sounding the Sun

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LONG-TERM GOAL

The long term goal of this project is to help ensure the safe and continued operation of DoD communication systems, both earth-based and those involving satellite links, by providing early detection of solar events known as coronal mass ejections (CME's) and enabling early warning to be given of CME's that appear likely to impact the earth. It has already been demonstrated, in January of 1997, that communication satellites can be disabled as a result of these CME's. More such events, and possibly many more such events, can be expected as we approach the solar maximum projected for the years 1999–2000 (see solar cycle figure below). In addition, there may be more extensive blackouts in the US, Canada, and other countries than have occurred during earlier solar maximums due to the recent trend of deregulation and consequent merger of many electric utilities into larger units. Note also that, while emphasis is given here to the impact of CME's on communication systems, operation of the GPS navigation system has never been tested during a solar maximum period, and it is conceivable that the strong CME's expected during the solar maximum of 1999–2000 will affect the GPS satellites and their communication links to the earth as well.

SCIENTIFIC OBJECTIVES

Earth-based methods of imaging the solar corona normally require the insertion of a shielding disk in the viewers to blank out the intensely-bright visible disk, whose light easily masks the corona. As a result, the components of the CME's detected by these earth-based systems are typically not those directed toward the earth and the CME's may or may not have an impact on the earth (and on satellites in space near the earth). The multinational SOHO satellite, which was launched in December of 1995, currently provides unmatched information about CME's, but it is not yet clear how well it can identify components of CME's that will impact upon the earth. The Large Angle and Spectrometric Coronagraph Experiment (LASCO) instrument on SOHO includes three different field of view coronagraphs. While the off sun-earth axis CMEs are easier to detect, on axis CMEs are also visible as expanding "halos" about the sun. The strong January 1997 CME event, which impacted the earth, was imaged by LASCO as just such a halo event. However, the much hyped April 1997 CME event, which was also seen as a halo, was apparently a close miss to the earth.

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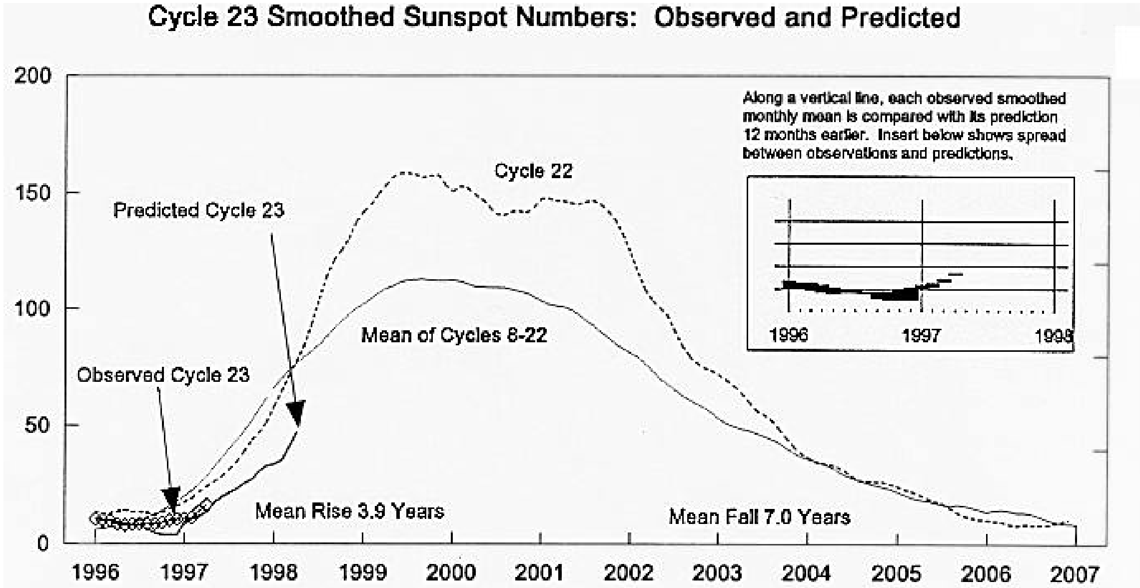

Figure 1. Plot of observed and predicted sunspot numbers for the present solar cycle 23. Also plotted, for comparison, are the sunspot numbers for the preceding solar cycle 22, and a mean plot of the sunspot numbers for cycles 8–22. The new solar cycle is just beginning to enter its active phase and solar activity will increase rapidly over the next two years [Plot from Solar–Geophysical Data , October 1997, published by the National Geophysical Data Center].

Figure 2 shows a SOHO composite plot for the CME that was in progress on November 6, 1997. The plot is rich in information, but it cannot tell us whether the gases in the CME will impact the earth, or, if they do, the extent of the disruption to earth-based communication systems. The objective of our "Sounding the sun" experiment is to detect earth-directed CME's by using existing earth-based HF (3-30 MHz) radar systems to obtain echoes from the sun that will be enhanced and have higher frequency doppler signatures following a CME.

APPROACH

Back in the late 1950's and early 1960's one of the participants in this project demonstrated that HF radar echoes could be obtained from the sun [*Eshleman et al*., 1960]. The HF experiments were successfully extended by J. James in Texas [*James*, 1968], but they ran into difficulties as the solar cycle approached its minimum and the HF radar cross-section of the sun decreased to levels approaching the size of the visible disk. Our approach is to duplicate these early experiments by using transmissions from over-the-horizon (OTH) radars. Initially, we hoped to use the Air Force's powerful OTH–B radar in Maine, but the system was mothballed before we could use it. We have since concentrated our effort on the possible use of either the ROTHR systems operated by the Navy in Virginia and Texas or the SRI International WARF system in the Central Valley of California. It is also possible that two of the systems could be used in combination, for example, with ROTHR being used for transmissions and WARF for reception, but there are timing problems associated with their separation in longitude that make this combined use more difficult than the use of a single system.

SOHO Composite: Coronal Mass Ejection
Credit: SOHO - LASCO - EIT Consortium, ESA, NASA

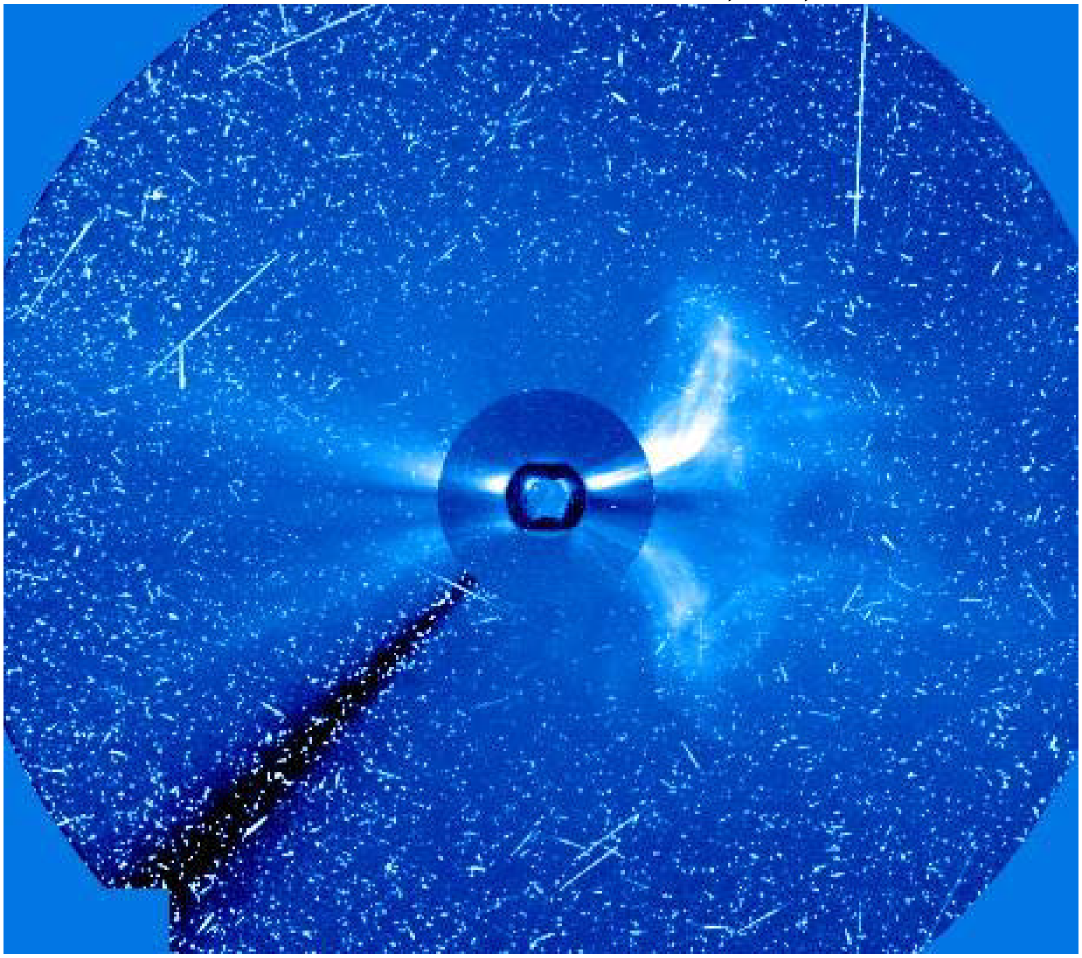

Figure 2. A complex composite image of an ominous and spectacular event – an expanding storm of energetic particles from the Sun – was constructed using data recorded by the SOHO spacecraft on November 6, 1997. Four images from two SOHO (Solar Orbiting Heliospheric Observatory) instruments have been nested to show the ultraviolet Sun at center and a large eruption of material from the right-hand solar limb. Known as a Coronal Mass Ejection or CME, the expanding cloud has become relatively cool and dark in the middle with bright edges still connected to the solar surface. High energy protons have peppered the SOHO detectors causing the crazed streaks and blemishes. The picture covers a region extending about 13.5 million miles from the Sun (32 Solar Radii). (Text courtesy of NASA)

WORK COMPLETED AND RESULTS

In support of the proposed “Sounding the sun” experiments, we have carried out several detailed estimates of the various losses likely to be involved in the experiments. In general, we obtain S/N ratios in the range of 1–10 dB for an entire transmit/receive sequence using one of the ROTHR systems, meaning that it should be possible to detect echoes from the sun. The estimate is less favorable for the WARF system; due to its lower transmitter power, detection of echoes from the sun will be marginal. However, all these estimates depend on two factors over which we have little control and few data: the

HF radar cross section of the active sun and the solar noise in the receiver bandwidth at the time of a CME.

Our estimates of these factors (the HF radar cross section of the active sun and the solar noise in the receiver bandwidth) are based on the experimental results reported by *James* [1968]. We also made use of the results of the studies by *Rodriguez* [1996] and *Bastian and Gary* [1997], the latter of whom comment relevantly that “the direct detection of CME’s at radio wavelengths is largely unexplored territory

One disadvantage of using OTR radars as solar radars is their largely horizontally directed transmit capability, which limits the times of “Sounding the sun” experiments either to a short time interval starting around dawn and ending about 1–2 hours later as the sun rises through the transmit beam, or to a correspondingly short time prior to sunset. Associated with this disadvantage is spreading of the transmitted signal as it enters and subsequently propagates through the ionosphere at a large angle of incidence. There will be similarly be spreading of the echo as it returns through the ionosphere. In addition to these problems, there are some extremely practical problems associated with the use of radars that are intended to detect objects moving at typical ocean vessel or aircraft speeds. That is, objects producing doppler shifts of less than about 25 Hz in the reflected signals. An energetic CME might well produce doppler shifts in the kHz or tens of kHz range. There are additional doppler shifts associated with the rotation of the earth and the radial component of its orbital motion. In general, these disadvantages and problems are manageable.

ROTHR is an operational facility and it is difficult to schedule time for experimental uses. The WARF system is used more extensively for research and it is therefore more flexible in its scheduling, but its transmitter is about 10 dB less powerful than those used in the ROTHR systems, which implies that any experiments conducted with it will be marginal (given our present knowledge of the experimental variables). Nevertheless, the operators of both ROTHR and WARF are interested in the possibility that the systems could be used to detect CME’s and thus provide an alternative and potentially important capability.

IMPACT/APPLICATION

It is our understanding that the most recent communication satellites do not generally use radiation resistant electronic components, due to their increased cost and limited availability. Given this situation, and the great increase in the numbers of communication satellites in orbit since the last solar maximum, we expect there to be a significant number of satellite casualties as the numbers and intensities of CME’s increase along with solar activity over the next few years. These CME’s will also impact upon ground communication links in what is now a relatively predictable manner, and they may also impact the GPS system. As a result, we anticipate increasing demand for a reliable method for detecting CME’s that will impact the earth. Our “Sounding the sun” experiments may well provide such a method. If so, they will have an important impact and an obvious practical application in global communications.

TRANSITIONS

It is too early for any transition.

RELATED PROJECTS

Researchers at NRL are also preparing radio experiments to detect CME's, or are interested in doing so [e.g., *Rodriguez*, 1996]. Through its involvement with SOHO's LASCO instrument (see above), NRL already has a significant capability for detecting CME's. Stanford University hosts a substantial SOHO activity and we have access to most SOHO data as soon as it is available. A combination of SOHO observations (as illustrated in Figure 2) and an HF radar capability would provide most if not all of the information required to provide useful warning of CME's that are likely to impact the earth.

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